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# ARIOS: An Acidification Ocean Database in the Galician Upwelling Ecosystem

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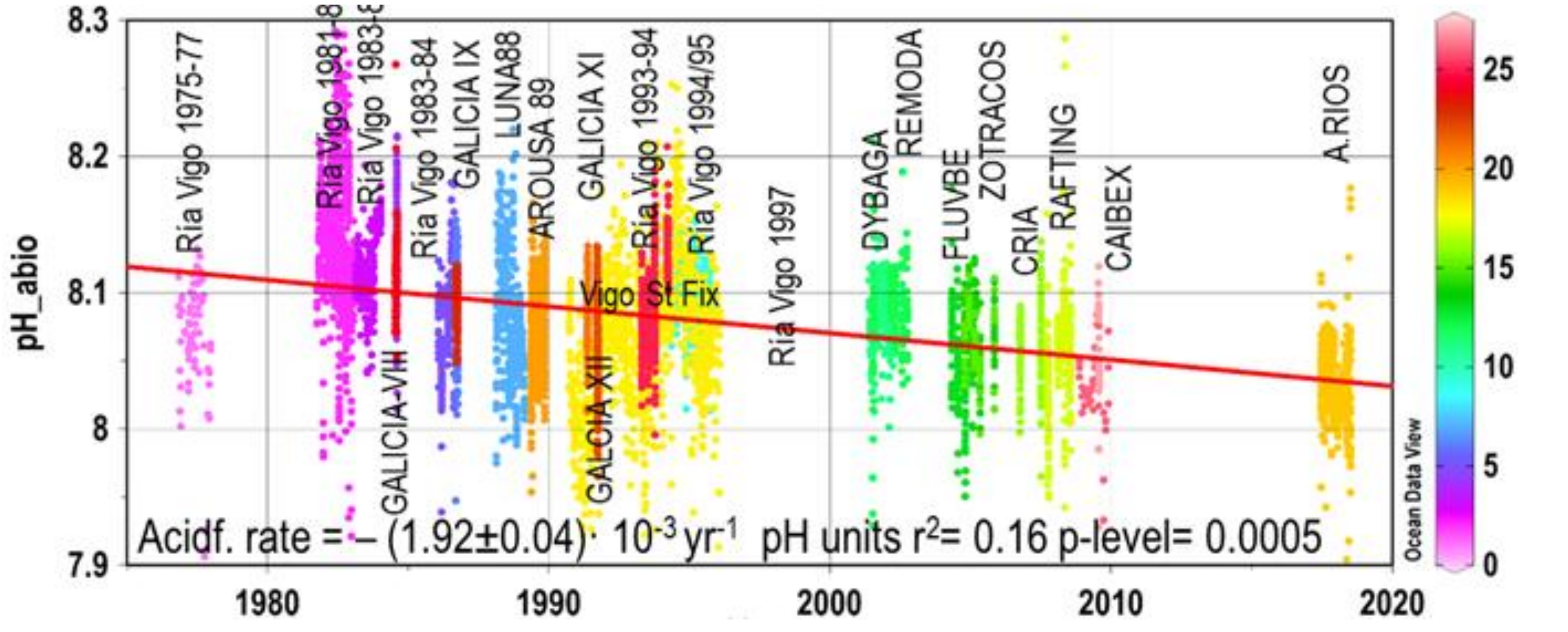
**Abstract:** Since 1976, pH and alkalinity measurements have been carried out with ancillary variables (temperature, salinity, nutrients and $O_2$) within the framework of 24 national projects in the Rias and Galicia platform. The objectives have evolved over time with the aim of understanding and modeling the primary production of a highly productive and strongly seasonal ecosystem where upwelling plays a key role. Different projects have intermittently measured the pH in all Galician Rias, coastal zone and oceanic region, from the surface to the bottom, mainly in summer and spring, but also monitored monthly time series and more frequently for some years. Here we have joined and harmonized the 24 databases to study long-term trends, as well as the pH variability observed according to ancillary variables. The present database, hereinafter called ***ARIOS (Acidification in the Rias and Iberian continental shelf)*** database, gathers information from 3357 oceanographic stations that add up to 17653 discrete samples during the last 40 years. This unique collection is a starting point for evaluating the ocean acidification in the Iberian Upwelling System to predict the future evolution of the pH as forced by the climatic change.

Preliminary gross acidification trend after removing the biogeochemical and thermal variability



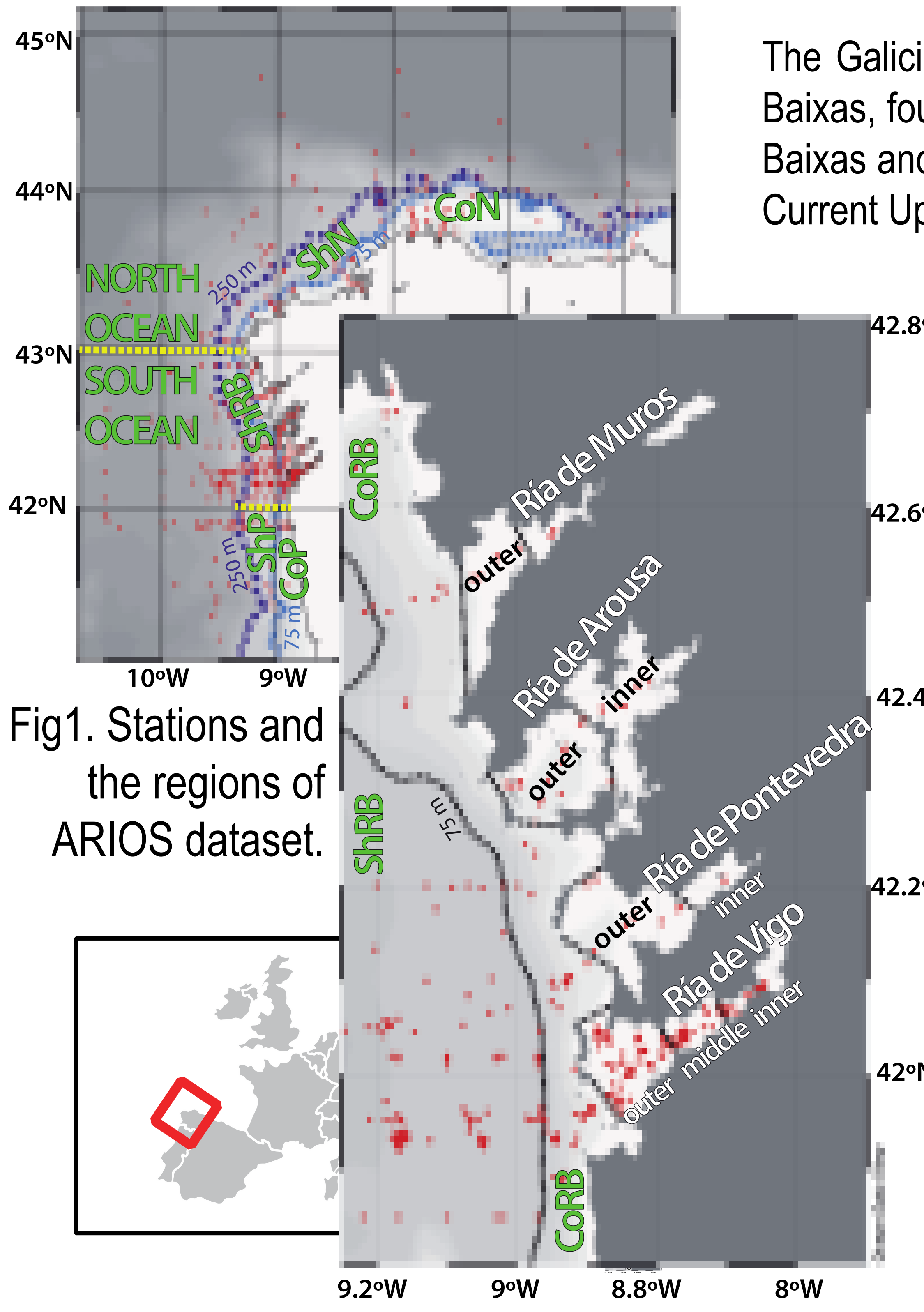
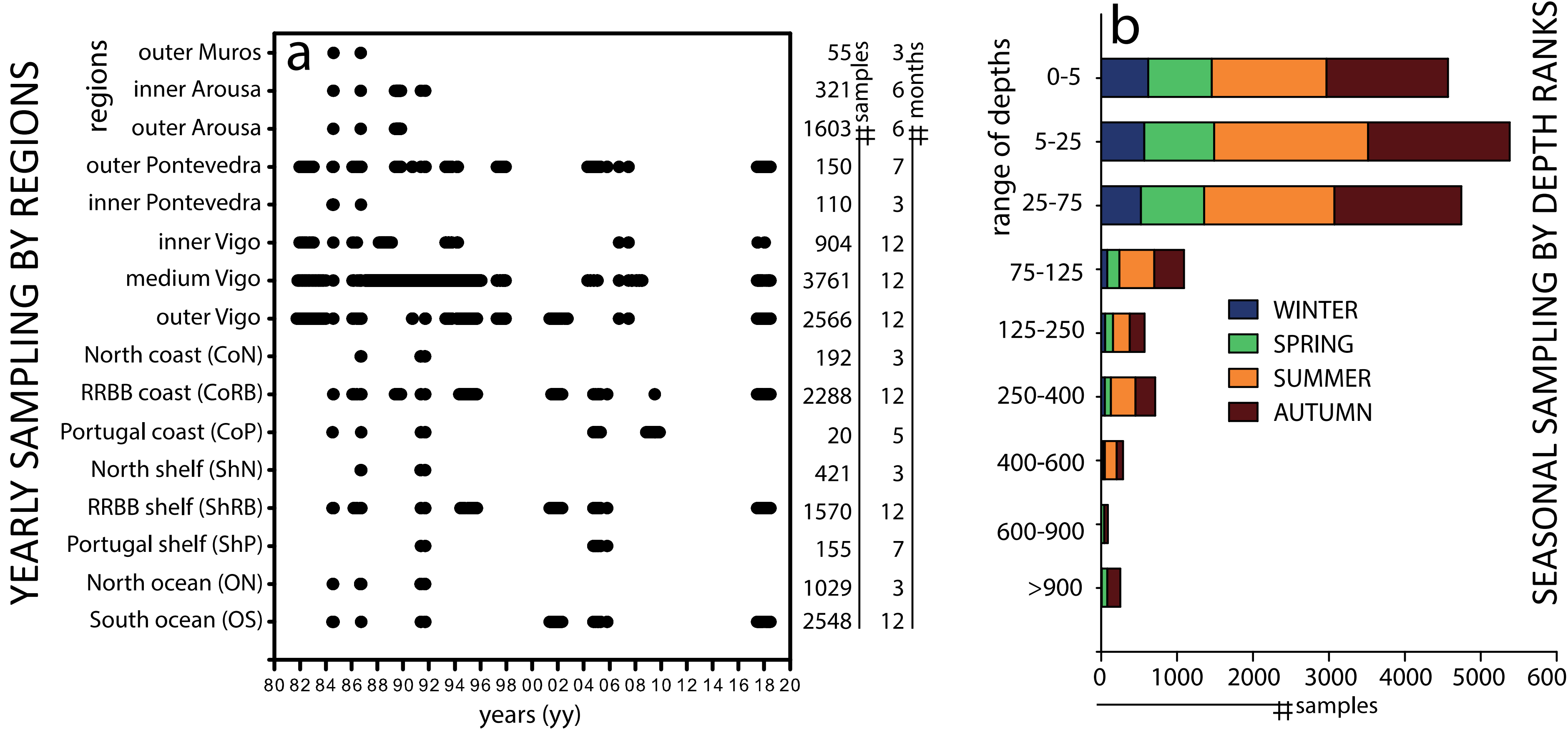


Fig1. Stations and the regions of ARIOS dataset.

The Galicia coastline located in the Northwestern Iberian Peninsula is mainly characterized by the presence of the Rías Baixas, four large (>2.5 km³) coastal embayments between 42ºN and 43ºN (Fig. 1). The water exchange between the Rías Baixas and the open waters is drastically affected by the coastal wind pattern as part of the upwelling system of the Canary Current Upwelling System (Wooster et al. 1976, Fraga 1981, Arístegui et al. 2004).

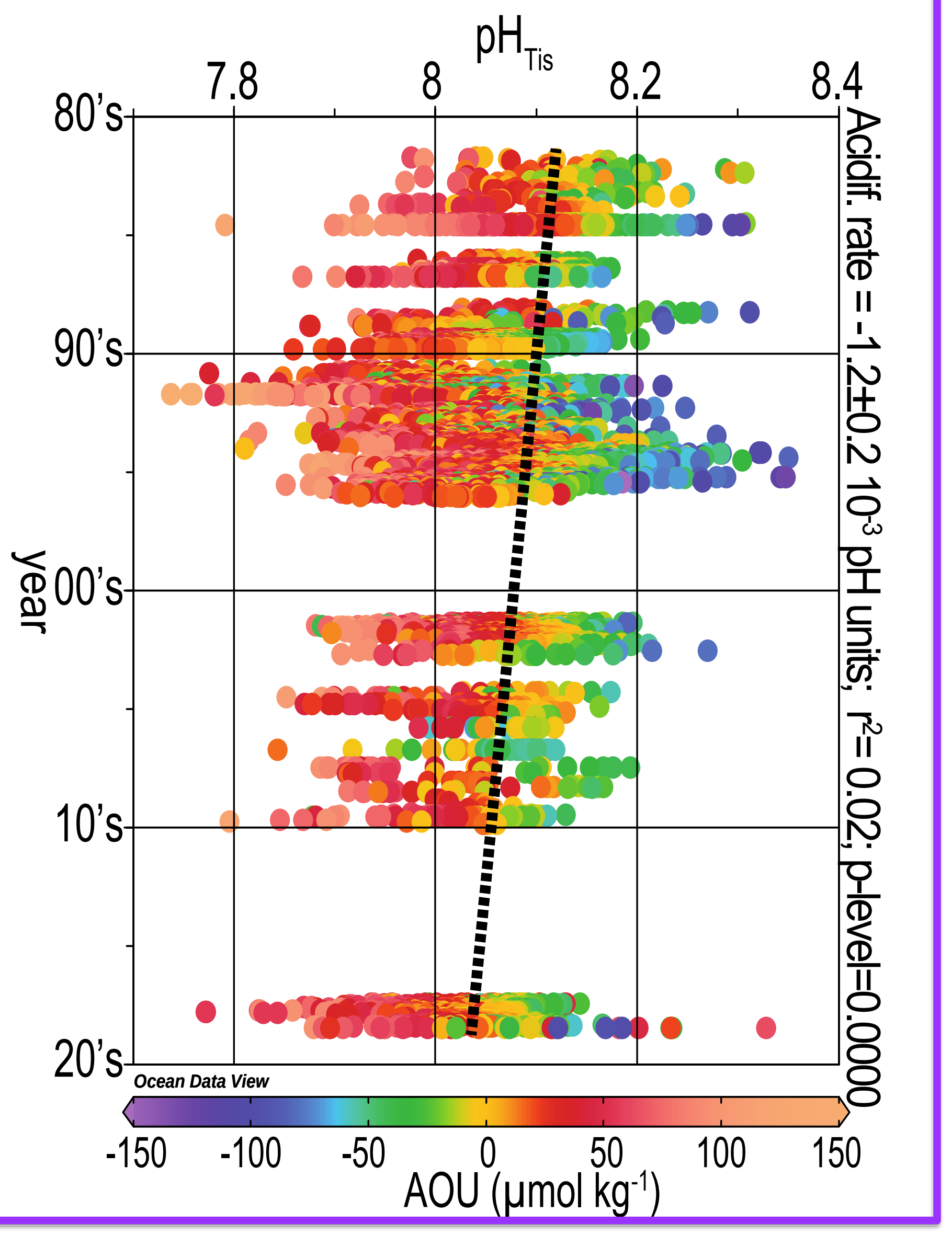


**REGIONS:** Different regions were identified in Fig 1 that represents different Rias and coastal area. The latitude of 43ºN (Finisterre Front, Fraga et al. 1982. Alvarez-Salgado et al. 2003) acts a oceanographic boundary between the northern and southern oceanic and coastal waters. A criterion of bottom depth of 250 and 75 metres was used to split the waters to the north of 43ºN into the North Ocean, North Shelf (ShN) and North Coast (CoN), respectively. The southern shelf waters were divided according to the latitude (42ºN) into Portugal shelf (ShP) and Rías Baixas shelf (ShRB) while the main Rias where divided using longitude limits into outer, middle and inner in the Ría de Vigo and outer and inner in the others (Ría de Pontevedra, Ría de Arousa, Ría de Muros). Southern waters between the 75-meter-isobath and the estuaries were identified as Portugal coast (CoP) and RRBB coast (CoRB).

**LONG-TERM TRENDS.-** The deseasonalized pH measurements showed a growing acidification towards the coast (Table 2). The interannual pH change of -0.0039±0.0005 yr-1 in the inner waters was about triple than -0.0012±0.0002 yr-1. Other acidification rates in different sites of the North Atlantic Ocean (Lauvset & Gruber, 2014; Bates et al., 2014) were within the acidification range found in the ocean and coastal domain of these waters.

| | $SS_{range}$ | $r^2$ | pH-trend | $r^2$ | p-value |
|---|---|---|---|---|---|
| OCEAN | 0.050 | 0.17 | -0.012±0.002 | 0.22 | <0.0001 |
| SHELF | 0.050 | 0.07 | -0.017±0.003 | 0.16 | <0.0001 |
| OUTER | 0.120 | 0.25 | -0.027±0.003 | 0.21 | <0.0001 |
| MIDDLE | 0.130 | 0.28 | -0.022±0.005 | 0.03 | <0.0001 |
| INNER | 0.260 | 0.48 | -0.039±0.005 | 0.34 | <0.0001 |

Another remarkable result of the ARIOS dataset was a interannual salinity rate of 0.0193±0.0056 psu yr-1 in parallel to a deoxygenation of -0.7±0.2 µmol kg-1 yr-1 and a long-term increase of the nitrate, phosphate and ammonium concentration of 0.0158±0.006 µmol kg-1 yr-1, 0.0076±0.0016 µmol kg-1 yr-1 and 0.0560±0.0011 µmol kg-1 yr-1, respectively .



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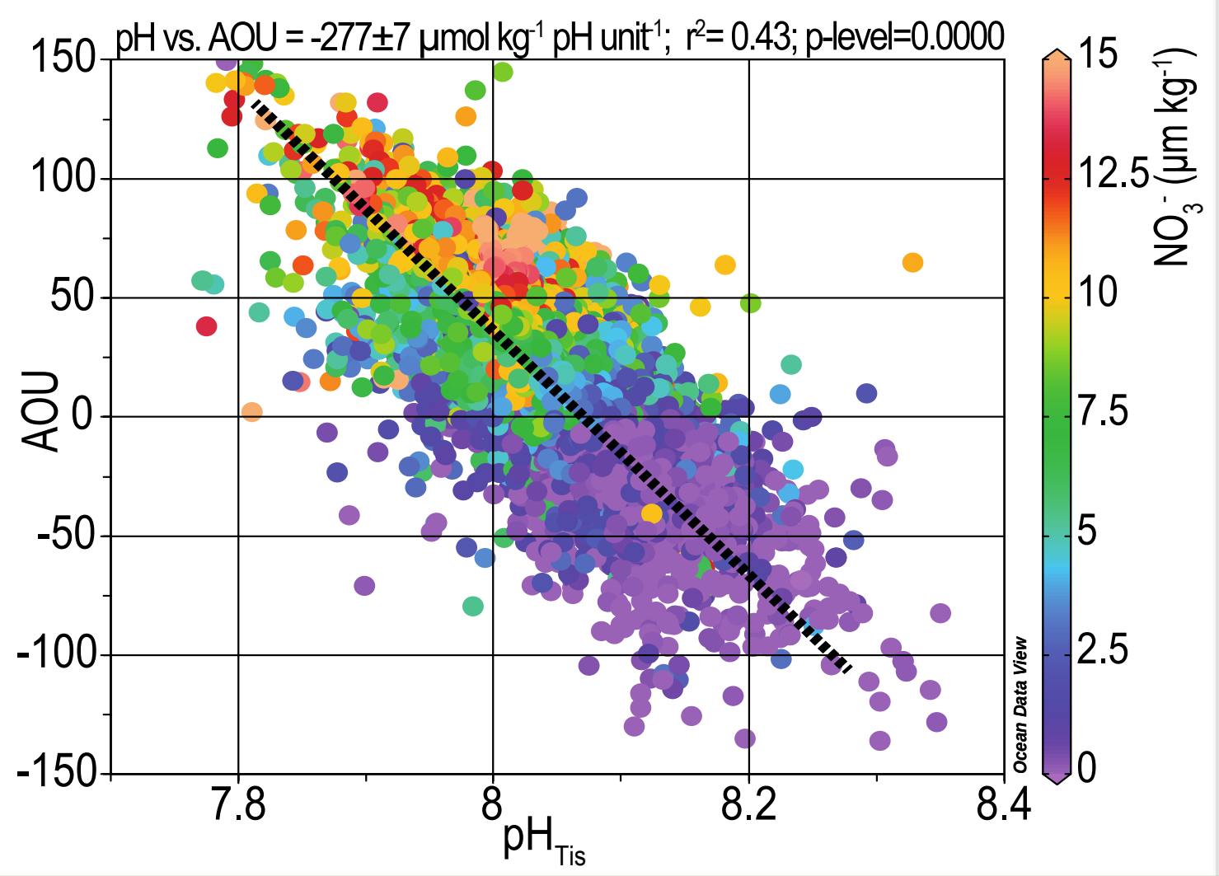
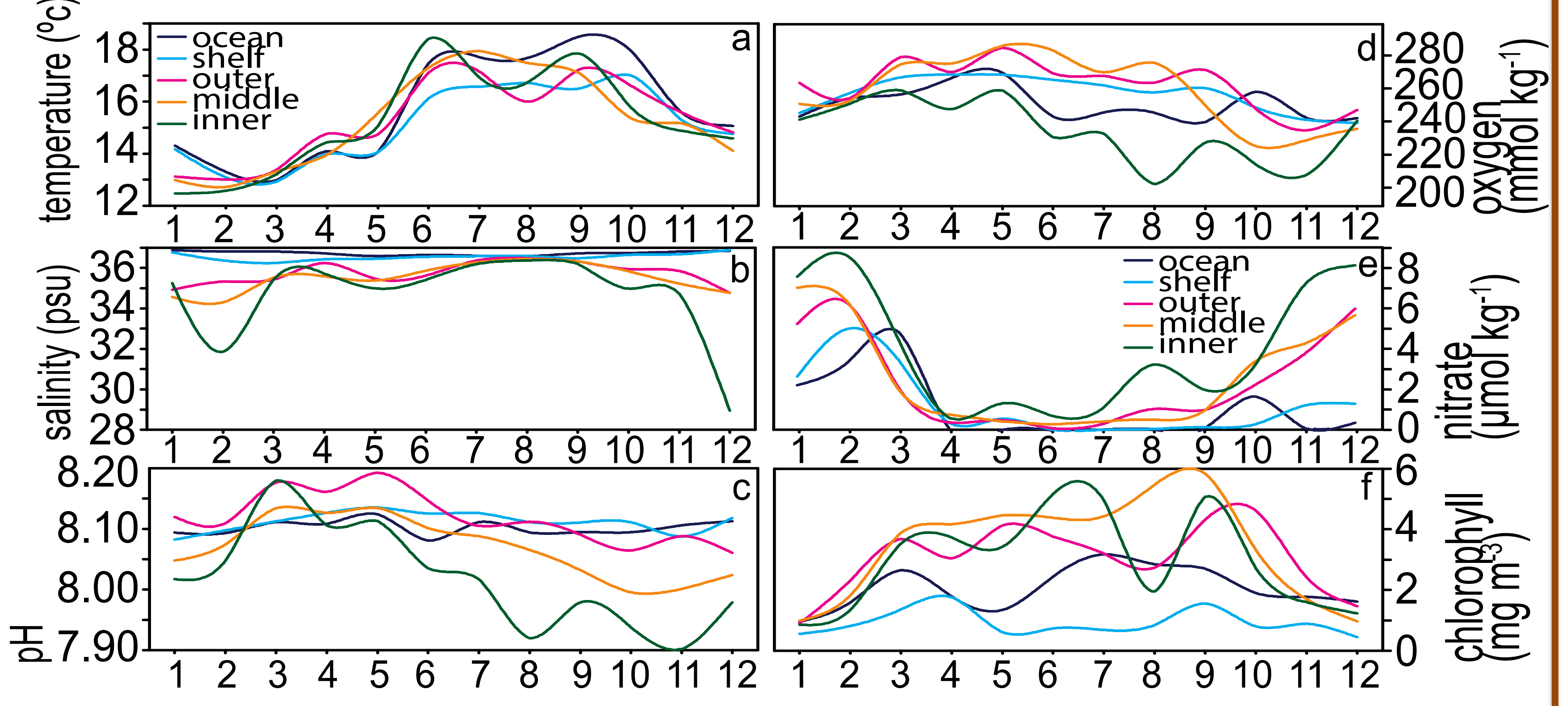
**NATURAL VARIABILITY.-** The strong biological activity of the upwelling systems is the main drivers of the pH variability (std±0.12 pH units) that is 50% higher of the 40-years-changed due to the anthropic drivers. In the figure the high correlation ($r^2$=0.66) between AOU (Apparent Oxygen Utilization and nitrate is shown.

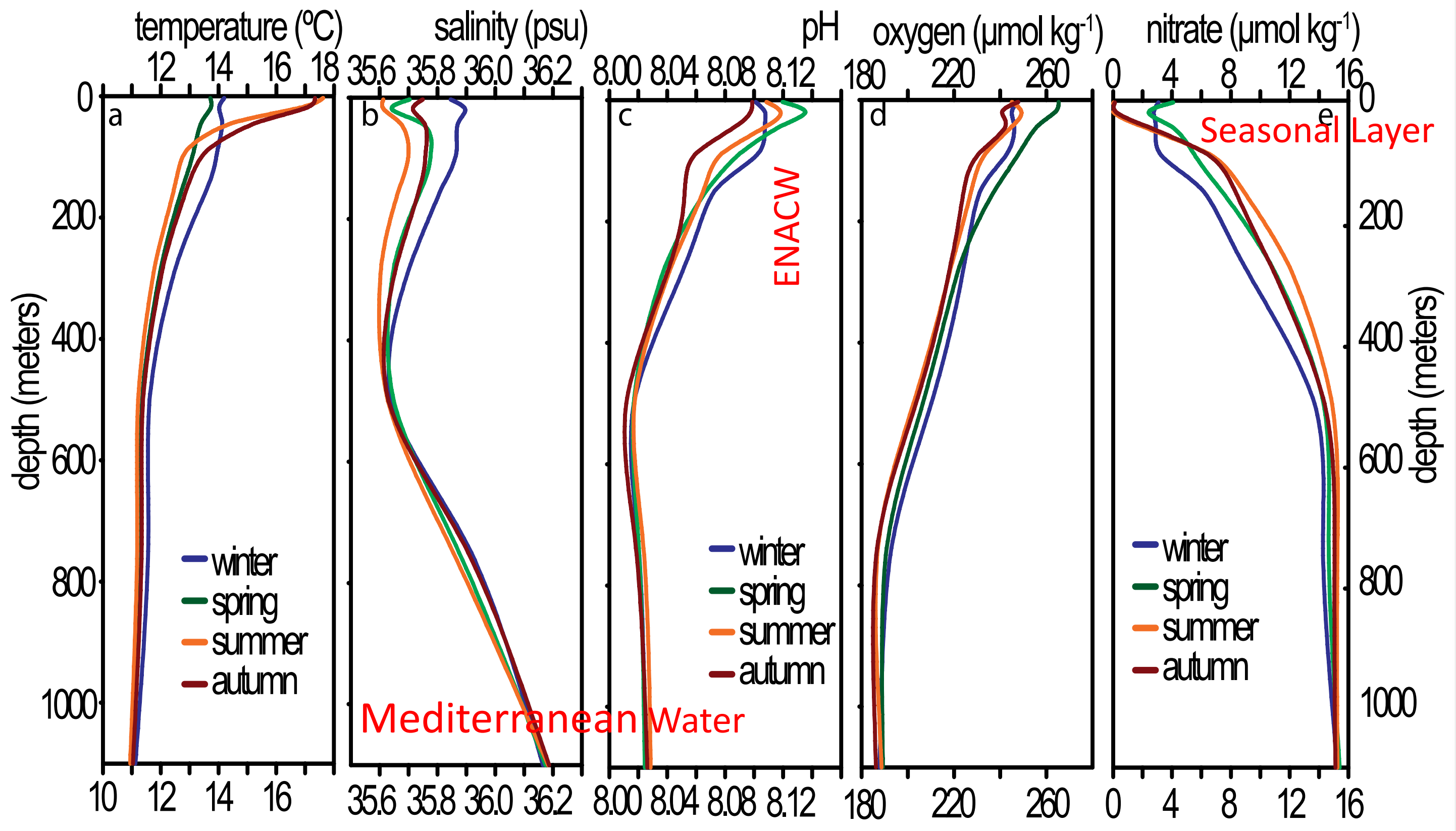


**SEASONAL CYCLE.-**The surface seasonal cycle of T,S, pH, $O_2$, nitrate and Chla in the five regions located between the inner of the Ría de Vigo and the ocean domain (Fig 1) is shown below.



Mean surface (0-5 meters) values of these variables was estimated as monthly filtered means accepting only values within two standard deviations.

**VERTICAL VARIABILITY.-** The vertical profiles in the ocean region between 41ºN and 43ºN was estimated for each oceanographic station as the mean value of the depth ranges described in Figure 2b. These measurements were gathered attending to the collection periods (December-February, March-May, June-August and September-November) and averaged to describe winter, spring, summer and autumn, respectively.



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